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Research Article

Post curing temperature effect on mechanical characterization of jute/basalt fiber reinforced hybrid composites

***Berkay KARAÇOR** [a,*] **and Mustafa ÖZCANLI** [a]*

[a]*Cukurova University, Faculty of Engineering, Dept. of Automotive Engineering, Adana, 01330, Turkey*

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ABSTRACT

Fiber-reinforced polymer composites have a fast-growing performance in many areas of engineering as a replacement for metallic materials due to their low density, low cost, specific mechanical characteristics, and lower energy consumption. The efficiency of fiber-reinforced polymer composites at high temperatures is an issue that requires to be well investigated before this type of composite can be used in important engineering fields. The aim of this study is to examine the change in mechanical properties of homogeneous and hybrid composites prepared from epoxy resin reinforced with jute fabric and basalt fabric at three diverse post-curing temperatures (50°C, 70°C, and 90°C). The vacuum- assisted resin transfer molding process was used to fabricate the laminated composites. The tensile strength and microhardness values of post-cured homogeneous and hybrid composite samples were determined by tensile tests and Vickers hardness measurements. A water absorption test was also performed to determine the water absorption capacity of the fabricated composites. After tensile testing of the fabricated structures, the effect of post-curing temperatures on the interaction of the fiber-matrix interface was investigated by scanning electron microscopy analysis. The results indicate that with increasing the post-curing temperature from 50 °C to 90 °C, an improvement of 45.48% in tensile strength and 34.65% in hardness is achieved for the hybrid composites. Moreover, the results of the water absorption test show that the increased post-curing temperature reduces the water absorption capacity of the hybrid composites by 3.53 times.

1. Introduction

In the automotive field, worldwide competition is a leading force in the emergence of improved and new materials, in order to reduce costs, maintain the ecological balance, and also maintain the share of commercial sales. In this competition, light mass designs are revealed and the desired requirements are met by the sector stakeholders' orientation to innovative materials [1]. During recent years, the usage of fiber-reinforced composite materials has been increasing for these innovative materials. Especially natural fiber reinforcements have created a remarkable recognition among researchers due to factors such as having low density compared to synthetic fibers, being cost-effective, being produced from natural sources, and being environmentally friendly [2]. Compared to synthetic fibers, the biodegradability of natural fibers, less damage to processing equipment and greater flexibility, improved composite surface quality in molded parts, and minimal health hazards are among the important advantages. For this reason, low-cost, light natural fibers such as abaca, sisal, hemp, flax, coconut, jute fiber can narrow the use of synthetic fibers in many areas [3], [4]. Moreover, natural fibers also have some critical disadvantages. The hydrophilic nature of natural fibers creates an issue in these cellulose-containing fibers that will significantly affect their mechanical features as well as their physical properties. Since the chemical nature of both the fibers and the matrix are diverse, it can lead to inoperative stress transmission during the formation of an interface of the produced composites [5], [6]. For this, the hybridization process of natural and synthetic fiber reinforcements contributes to the usage of natural fibers in structural applications. While the low mechanical characteristics of natural fibers are improved by the hybridization process, the cost of the other reinforcing element used, the damage to the environment, etc. factors are minimized [7]. Jute fibers are one of the most cost-effective natural fibers cultivated in countries such as

* Corresponding author. Tel.: *+90-322-338-6600*; Fax: +90-322-338-6945
E-mail addresses: bkaracor@cu.edu.tr *(B. Karacor)*, ozcanli@cu.edu.tr *(M. Ozcanli)*
ORCID: 0000-0001-5208-366X *(B. Karacor)*, 0000-0001-6088-2912 *(M. Ozcanli)*
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India, China, Nepal, Bangladesh, and Thailand. In addition, it has many application areas such as aircraft, furniture sector, including the automotive sector. The high strength/weight ratio, good insulation features, mechanical features, and thermal features of jute fibers are effective in the preference of jute fibers in these areas. Whereas the lower density, specific strength per unit cost, specific stiffness, and strength in jute fibers are comparable to glass fibers, it is better than glass fibers in terms of specific modulus, besides jute is superior in terms of cost per module [8]–[10]. The use of light, low-cost natural fibers in many industries, including the automotive industry, is replacing a large part of the traditional materials used. Especially in automotive, the reinforcement of natural fibers to interior and exterior parts not only gives ecological sensitivity and recyclability without sacrificing safety but also affects fuel economy by reducing vehicle weight. Thus, the global CO_2 balance will not only be kept at a stable level even so will contribute to global sustainability by reducing dependency on petroleum-based products [11]–[13]. One of the fibers that have the potential to be used in the automotive sector is basalt fibers from the mineral fiber class. When basalt fibers are compared with vegetable natural fibers, it is seen that they have a higher modulus of elasticity and tensile strength. It is a green material that does not harm the ecological environment, has a cost of less than one-tenth of carbon fiber, and exhibits notably diverse characteristics from other fibers. Basalt rock fibers are nonflammable and explosion-proof, as well as atoxic reaction with water or air. It is stated that basalt-based composites can be used instead of steels and known reinforced plastics. Basalt fibers have good moisture, fatigue, and vibration resistance and exhibit superior characteristics in terms of acoustic insulation compared to other fibers [14]–[17]. However, many determinants like the type of matrix used in the production of composites, the filling material, the orientation of the fabric, and the production methods affect the mechanical characteristics of the hybrid composite. Researchers use various techniques to enhance mechanical characteristics in hybrid composites. They discovered that with this applied modification and chemical treatment, the fibers improved in mechanical characteristics, water resistance, and fire resistance compared to untreated composites [18]. Cangül et al. [19] conducted an experimental study to crosscheck the water solubility capacity and water absorption characteristics of the resins using four distinct resins. They commented that water solubility and water absorption in composite resin matrices are seen as one of the critical issues that change the chemical, physical, and mechanical structures of resins, the matrix and filler structure of the resin should be carefully examined to eliminate this effect. An accelerated aging effect has been created on composite laminates, and the mechanical responses that occur in laminates over time have been investigated. In the research, in which jute and basalt fibers were used as reinforcement elements with two different sequencing orders, it was observed that the hybridize operation of basalt fibers to jute fibers significantly increased the resistance to environmental aging [20]. Surana et al. [21] examined the mechanical and vibration characteristics of the samples they prepared using basalt fiber and epoxy. Whereas it was observed that 2% filling material gave the best results in the tensile test, it was understood that 4% filling material was the critical value in the vibration test. Kumar and Singh [22] examined the impact of fiber orientation on impact strength, flexural strength, tensile strength, and hardness in basalt fiber reinforced epoxy hybrid composites. In the mechanical test outcomes, the best values were obtained for the composite specimens with a fiber orientation angle of 90°, as the composite specimens with a fiber orientation of 45° showed the lowest values. In an investigation of Darshan and Suresha [23], in which basalt fiber was hybridized with silk fiber, it was aimed to produce new composite materiel by incorporating basalt fiber in different weight ratios into silk fiber composites. It has been found that the composites composed of 25% by weight silk fiber and 25% by weight basalt fiber give the most optimum mechanical properties for use in structural engineering applications. In another search in which basalt and jute fiber were used, the walnut shell was mixed with epoxy resin in weight ratios between 0% and 15% (0%, 5%, 10%, 15%) to form composite materiel. It was found that the mechanical features were improved in the composites with higher walnut shell ratios by weight [24]. In an investigation in which nano graphene was used as filling material, the friction coefficients and specific wear rates of the products produced by producing homogeneous jute fabric composite, homogeneous basalt fabric composite, and hybrid basalt/jute fiber composite were investigated. In the results, the hybrid composites with the lowest specific wear rate and coefficient of friction are those containing 0.4% by weight graphene [25]. The mechanical characteristics of composite laminates in which jute fiber is combined in different ratios (20%, 30%, and 50%) were analyzed both experimentally and numerically. It was expressed in the results that the mechanical properties improved as the Jute fiber ratio increased in the combination [26]. In the microscopic and macroscopic examination of fiber metal layer composites in four different arrays consisting of basalt, jute, and aluminum, it was found that weak adhesion occurred between jute fibers and aluminum in the interfacial connections. It was stated that the poor adhesion of jute fibers with epoxy was the basis of the loss in mechanical features [27]. By the time these studies in the literature are examined, it has been observed that there is not enough research to investigate the effect of temperature on composite materials. It is known that temperature is a very important parameter in composites both during production and during operation. Almeida-Chetti et al. [28] investigated how curing temperatures on four different composite resins influence the modulus of elasticity and flexural strength of the resins. It was determined that there was an augment in both the modulus of elasticity and the flexural strength of the post-cured composites. In the search made by Singh et al. [29], it was investigated how the post cure temperature varying between 80°C and 130°C would affect the mechanical characteristics of composites produced with jute fiber and epoxy resin. Whilst there was an increment in elastic modulus, flexural strength, and tensile strength up to 100°C, temperatures after 100°C had a negative impact on mechanical properties. The impact strength, on the other hand, had the highest value when the post curing temperature was at 80°C, while its increase from this temperature negatively affected the impact strength. It has also been found that the post-curing process improves the ratio of the material's loss modulus to the storage modulus, resulting in the development of the fiber matrix interface [30]. The effects of various operating temperatures during production were investigated, although the effects of different curing temperatures have been discussed in previous studies, it was found that the study on the effects of post-curing on tensile strength, hardness, and water absorption values of Jute and Basalt fibers and their hybrid composites is lacking in the literature. In this work, pure jute composites, pure basalt composites, and hybrid jute/basalt composites were fabricated using Jute and Basalt fabrics and epoxy resin. The fabricated composites were exposed to post-curing at 50°C, 70°C, and 90°C for 1 hour. It was investigated how these three different post-curing temperatures on the fabricated products in tests of tensile strength, hardness, and water absorption were scrutinized. The microscopic effects of the three different post-cure temperatures on the manufactured composites were also analyzed using scanning electron microscopy.

2. Material and Methods

2.1 Material

Jute plain woven texture and Basalt plain woven texture were supplied by companies in Istanbul. These textures were utilized as reinforcement materiels. These texture characteristics used in this research are listed in Table 1. The fabric specimens are indicated in Figure 1. Also, the fabric stacking sequences are indicated in Figure 2.

In this work, the related hardener LH160 and the epoxy resin L160 were utilized as matrix material. The hardener and epoxy resin were procured by Kompozitshop. The specific characteristics of the matrix assembly are listed in Table 2. A weight ratio of 100:25±2 was chosen for the mixture of epoxy resin and hardener, taking into account the values given by the manufacturer and data from previous studies.

In this research, twenty-seven composite samples were prepared for homogeneous and hybrid composite structures with two different fabrics and three different post-curing temperatures. The fabrics were placed with unidirectional and inter-ply structure. The pattern names given to the samples for the composite laminates fabricated are listed in Table 3.

After the samples were cured in a furnace at 50°C, 70°C, and 90°C for 1 hour, the cutting process was carried out with a waterjet device in the test sizes defined in the norms.

Table 1. Fabric characteristics [31], [32]

Fabric	Weight (g/m²)	Thickness of fabric (mm)	Warp (tex)	Weft (tex)
Jute fabric	250	0.4	-	-
Basalt fabric	200	0.2	200	200

Figure 1. Fabric specimens: a) Jute fabric b) Basalt fabric

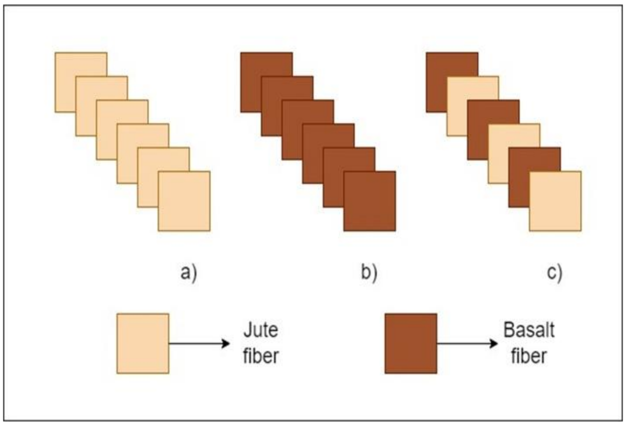


Figure 2. Fabric stacking sequences of: a) Jute fabric b) Basalt fabric c) Jute/Basalt fabric hybrid structure

Table 2. Hardener and epoxy characteristics [33]

	LH160 Hardener	L160 Epoxy
Density (g / cm³)	0.96-1.0	1.13-1.17
Viscosity (mPas)	10-50	700-900
Actuation temperature (°C)	-	60 / +50 except heat treatment -60 / +80 by performing heat treatment
Refractor index	1.520-1.521	1.548-1.553
Mensuration circumstances	25°C	25°C

Table 3. Naming of prepared specimens

Pattern name	Textile versions
J	Jute fabric
B	Basalt fabric
JE	Jute fiber reinforced homogeneous composite
BE	Basalt fiber reinforced homogeneous composite
JBE	Jute/ Basalt fiber reinforced hybrid composite

2.2 Method

The VARTM technique has been utilized in the manufacturing of hybrid composites comprise of epoxy resin reinforced with jute and basalt fabric. In this technique, a vacuum force is the main factor to remove the air that may be in the reinforcement material and to ensure that the resin enters the mold. Ensuring tightness is the most critical step in the fabrication process. All samples were produced at 20°C ± 2°C and a pressure of 1 bar. First, the production area was surrounded with vacuum sealing tape, according to the dimensions of the fabrics, which were cut according to the standard dimensions. After the fabrics are lined up on the area in a predetermined order, peel fabric, infusion mesh, and vacuum foil are laid on top in order. Hose connections for resin inlet and outlet were then connected to the system, and the resin prepared in the determined mixing ratios was infused into the system. The vacuum pump was operated at a pressure of one bar for approximately two hours until excess resin movement ceased. The samples were cured within 24 hours after the pump was turned off. The samples taken after 24 hours were cured in a furnace at 50°C, 70°C, and 90°C for 1 hour and then prepared for waterjet cutting.

2.3 Tensile Testing

The tensile test was carried out to specify the mechanical features of the composite products produced in the scope of the study. Specimens with 250 mm length,25 mm width and 2.5 mm thickness were prepared for the tensile test according to the ASTM D3039 standards. The tests were performed using the ALSA Hydraulic test device in KOLUMAN Automotive Industry Laboratory. ASTM D 3039 rule was taken into account when tensile testing the materials, and the test was carried out by adjusting the cross-head speed to 2 mm/min [34]. The apparatus with a capacity of 98000 kN load cell was utilized to construct tensile tests as is indicated in Figure 3. The experiments were performed at 20°C ± 2°C temperature and the sample sizes were entered into the computer program before starting the test. After the test, the values of tensile strength, modulus of elasticity, and strain rate values of the manufactured products were reached. From the average of the results of the 5 samples tested for homogeneous and hybrid composite structures, the values related to the tensile strength of the manufactured specimens were obtained.

2.4 Hardness Testing

The hardness value of the composite products manufactured in the study was assigned by the Vickers hardness method. The measured Vickers hardness values are directly related to the applied load and the area created by the impression on the test surface of the material. The ASTM E92-17 standard was taken as a reference when measuring the hardness of the samples, and the measurement was made by selecting the force value of 0.2 kgf using an AOB Lab product machine. Specimens with 70 mm length,70 mm width and 1.5 mm thickness were prepared for hardness test. [35]. Fifteen hardness measurements were performed on the prepared sample surfaces and the average of the 15 values was recorded as the Vickers hardness value of the composite product.

Figure 3. Tensile testing machine

2.5 Water Absorption Analysis

The objective of this analysis is to specify the water absorption capacity of the samples produced in normal water, taking into account ASTM D-5229 standards [36]. For the water absorption test, the samples were produced in the dimensions of 100 mm length, 100 mm width and 2 mm thickness and prepared for the test. The three composite samples were tested with water during their stay in the container. First, the dry weights of the produced products were measured on a digital balance, then the samples were immersed in water for 120 h and the samples were weighed at regular intervals and the amount of water absorbed was noted periodically. The test was implemented at room temperature. Tap water was used in the containers in which the samples were placed. The preference for tap water is because there are also studies using tap water, and these studies also yield close results to real results.

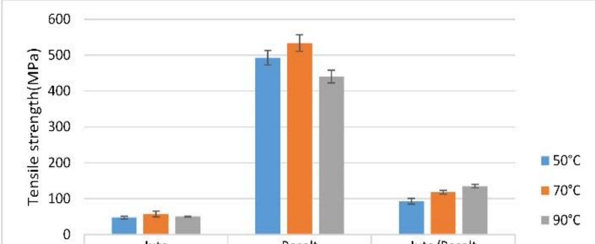
2.6 Morphological Analysis

The SEM FEI Quanta 650 Field Emission device was used to examine and analyze the surface morphology of the produced composite samples. The surface conductivity of the samples was increased by gold spraying and the surface coating was performed. The aggrandizement capacity of the instrument is in the range of 6-1,000,000 x times and can be operated at 30 kV. With this analysis, it will be possible to observe the fracture surface of the composite samples and explore the interfacial properties such as fiber-matrix interactions, matrix cracks in the material, fiber shrinkage, fiber breakage, and fiber-matrix bond separation.

3. Result and Discussions

3.1 Tensile Test Results

In the scope of this research, tensile test outcomes are given in Figure 4. The standard deviations in the test results were ±3.94, ±19.92, and ±7.82 for the J, B and JB samples at 50°C, ±7.87, ±22.96, and ±5.08 for the J, B and JB samples at 70°C, respectively. These deviation values for 90°C are ±1.06, ±17.91, and ±4.78 for J, B and JB samples, respectively. According to the results obtained, the post-curing temperature being 90°C instead of 50°C caused an increase in the tensile strength value of hybrid jute/basalt composites and homogeneous jute composites, while a decline in tensile strength value was observed in homogeneous basalt composites. Increasing the post curing temperature above 70°C in homogeneous jute and basalt composites had a negative impact on the tensile strength. It has been stated in the studies that this situation is associated with the glass transition temperature of polymers. The outcomes of the study displayed that the tensile strength value of the samples produced did not change when the glass transition temperature was exceeded in the material.



	Jute	Basalt	Jute/Basalt
50°C	47.31	493.09	92.72
70°C	57.35	533.60	117.92
90°C	50.28	440.55	134.89

Figure 4. Tensile test results

In a study in which the hybridization process of jute fiber was performed, it was expressed that the tensile strength and flexural strength values declined by rising the post cure temperature from 60 °C to 90 °C [37], [38]. In this study, a tensile strength increment of 21.22% in homogeneous jute composites and 8.21% in homogeneous basalt composites was observed at post-curing temperature increasing from 50 °C to 70 °C. In hybrid jute/basalt composites, on the other hand, increasing post-cure temperature from through 50 °C to 70 °C provided a tensile strength increase of 27.18%, as increasing post-cure temperature from 70 °C to 90 °C provided a 14.39% increase in tensile strength. Besides, compared to homogeneous jute composites, the tensile strength of hybrid jute/basalt composites increased by 1.96, 2.06, and 2.68 times at 50 °C, 70 °C, and 90 °C post curing temperatures, respectively, with hybridization process. This reflects the positive impact of increasing the post-cure temperature on the tensile strength values of the hybridization process.

Table 4 displays the elastic modulus and elongation rate results of produced composites. As the elastic modulus results are evaluated, the rise in post-cure temperature from 50°C to 90°C in parallel with the tensile strength value results had a positive effect on homogeneous jute composites and hybrid jute/basalt composites, while it had a negative effect on homogeneous basalt composites. In the results of the elongation rates, the impact of post-cure temperature increase was similar to the tensile strength and elastic modulus results. In the study where the post curing temperatures at 60 °C, 80 °C, and 100 °C were analyzed using jute fabric, it was found that the elastic modulus value increased with increasing post curing temperature [39]. Rising the post-cure temperature from 50 °C to 90 °C led to an elastic modulus increase of 1.58 times in homogeneous jute composites and 1.44 times in hybrid jute/basalt composites. Whilst these rates tend to increase by 1.02 times at post-curing temperatures rising from 50°C to 70°C in homogeneous basalt composites, post curing temperature increasing from 70°C to 90°C caused a 1.14 times decline in elastic modulus value.

Table 4. Elastic modulus and elongation rate results

Post-cure temperature	Elastic modulus (MPa)			Post-cure temperature	Elongation rate (%)		
	Jute	Basalt	Jute/Basalt		Jute	Basalt	Jute/Basalt
50°C	993.2±21.52	5749.2±24.78	1227±49.13	50°C	4.22±0.22	9.76±0.27	6.26±0.39
70°C	1139.4±31.76	5892.8±21.48	1464.4±65.8	70°C	4.24±0.23	9.94±0.27	6.52±0.18
90°C	1567.4±18.9	5148.8±20.04	1768.2±62.57	90°C	4.56±0.13	9.3±0.27	6.34±0.17

In the previous studies, it has been found that the features of tensile strength at different temperatures applied to hybrid composites using basalt fibers vary depending on the temperatures [38]. Elevated the post-cure temperature from 50°C to 90°C in percent elongation rates resulted in an increase of 1.01 times in hybrid jute/basalt composites and 1.08 times in homogeneous jute composites.

3.2 Hardness Test Results

Figure 5 gives the microhardness results of prepared composites in this research. It indicates that Vickers hardness value increases with increasing post curing temperatures both in homogeneous composites and hybrid composites. It can be shown that the enhanced cross-links formed by the post-curing process in the polymer matrix resin make the composite structure more robust, causing an increase in the hardness value due to the increased post-curing temperature. In a study in which the hardness test was performed by rising the post-cure temperature from 40°C to 80°C, it was determined that the hardness value enhanced with the post-cure temperature [40]. Increasing the post curing temperature from 50°C to 90°C resulted in an increase of 36.15%, 19.53%, and 34.65% in Vickers hardness values for JE, BE, and JBE, respectively. As the post-cure temperature is increased from 50°C to 70°C, these rates are 28.86%, 12.6%, and 7.97% for JE, BE, and JBE, respectively, in Vickers hardness values. Increasing the post-cure temperatures from 70°C to 90°C increases the Vickers hardness values by 5.66%, 6.16%, and 24.71% for JE, BE, and JBE, respectively. While the standard deviation values were ±23.67, ±20.07, and ±25.05 in J, B and JB samples, respectively, at 50°C, they were ±10.32, ±22.3, and ±27.53 in J, B and JB samples at 70°C. These values are ±12.64, ±14.24, and ±20.55 for J, B and JB samples at 90°C, respectively.

3.3 Water Absorption Analysis Results

Figure 6, 7 and 8 gives the water absorption analysis outcomes of produced samples. Because of the hydrophilic nature of jute fibers, the highest water absorption was observed in homogeneous jute fiber composites. Basalt fibers from mineral fibers did not absorb as much water as jute fibers. In previous studies, basalt fiber was successful in preventing water penetration into the fiber-matrix interface by showing better water-repellent behavior in basalt hybridization application in composites [41]. In JE composite structures, the water absorption rates of 7.31%, 6.14%, and 8.94% were observed in the samples applied post-cure temperatures of 50°C, 70°C, and 90°C, respectively. These increase rates were found as 0.42%, 0.25%, and 0.24% in BE structures at post-cure temperatures of 50°C, 70°C, and 90°C, respectively. In JBE structures, water absorption was 1.66% at 50 °C, 0.74% at 70 °C, and 0.47% at 90 °C. From this, it is observed that the water absorption of the hybrid composites made with basalt fiber and jute fiber is significantly less, and the water absorption of the jute fibers is significantly inhibited by the basalt fibers. Water absorption is also affected by the cell wall, the lumen, the gap between fiber and resin, and poor interfacial bonding [42]. It is obtained from the results in the graph that the water absorption decreases with the increase of post-curing temperatures. This is an indication that the polymer epoxy matrix forms stronger bonds as the post-cure temperature rises, reducing the water absorption capacity of the fibers.

3.4 SEM Analysis Results

The images from Figure 9 to Figure 17 show the SEM analysis images of the structures after the tensile test performed after the post-cure temperatures of 50°C, 70°C, and 90°C were applied. SEM analysis image of homogeneous jute fiber composites applied at 50°C post curing temperature is given in Figure 9.

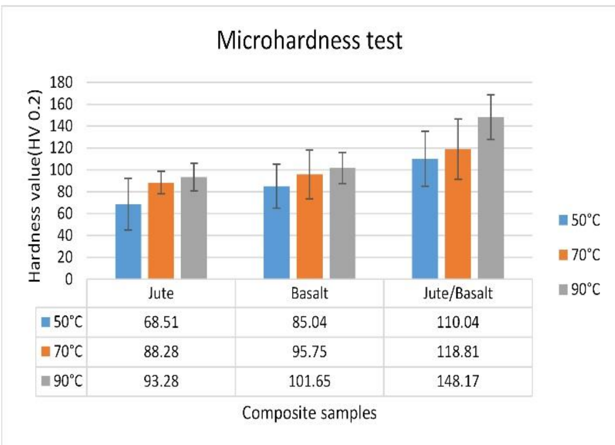


Figure 5. Hardness test results

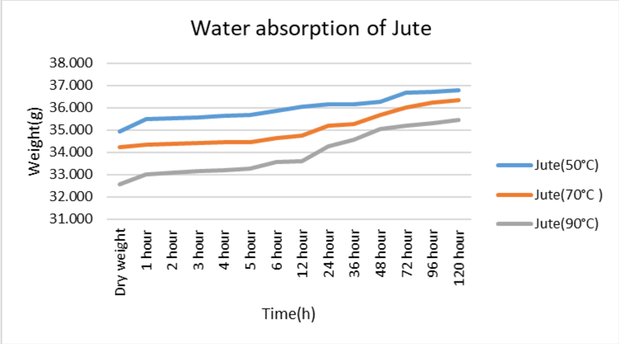


Figure 6. Water absorption analysis results of Jute composite

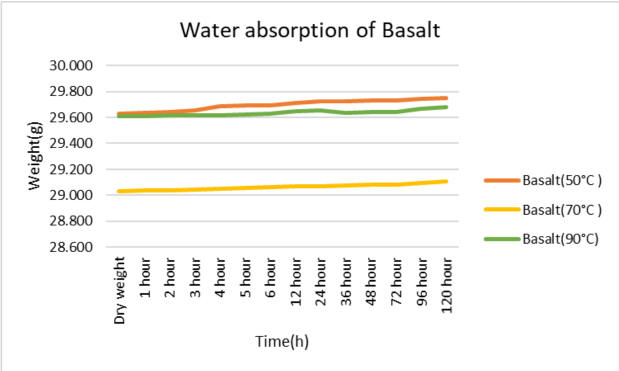


Figure 7. Water absorption analysis results of Basalt composite

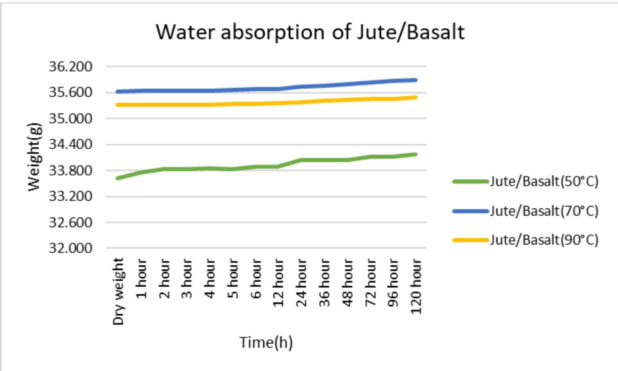


Figure 8. Water absorption analysis results of Jute/Basalt hybrid composites

Whilst voids are seen in the JE structure, there are almost no void structures in the BE structures in Figure 10. Fiber shrinkage and fiber elongation were detected in JE structures, and homogeneous fiber breaks were detected in BE structures. In the JBE structures in Figure 11, it was understood that due to the strong bonding of the matrix resin and the fibers, no voids were observed, fiber shrinkage and elongation of the jute fibers were observed, while basalt fibers broke into fiber bundles. In the samples after the tensile test, fiber breaks and fiber shrinkage due to mechanical load are also observed at different post-curing temperatures in the hybridization of jute fiber with different fabrics [43]. It is seen that the jute fiber structures in Figure 12 show fiber shrinkage. In the comparison of BE structures in Figure 13 and Figure 11, it was determined that basalt fibers were broken in bundles and homogeneously and did not show fiber shrinkage or elongation.

By the time the JE structures in Figure 15 are checked against the JE structures in Figure 9 and Figure 12, it was found that the gaps between the matrix resin and the fibers increased. This can be expressed by the fact that natural fibers and matrix structures have different chemical structures and do not form a good bond between them [30]. In the comparison of BE structures in Figure 13 and Figure 16, it was seen that the resin did not completely cover the matrix in BE structures that were post-cured at 90 °C, indicating that there was not as much bonding between the matrix and the resin as in BE structures that were post-cured at 70 °C. This explains why the tensile strength value of Basalt fiber samples when 90°C post curing temperature is applied is less than the tensile strength value of the samples for which 70°C post curing temperature is applied. As the JBE structures in Figure 17 and Figure 14 are checked against the structures in Figure 11, it was observed that resin and fibers showed good adhesion. Moreover, less fiber breakage and shrinkage were observed in Figures 14 and 17 compared to the JBE structures in Figure 11.

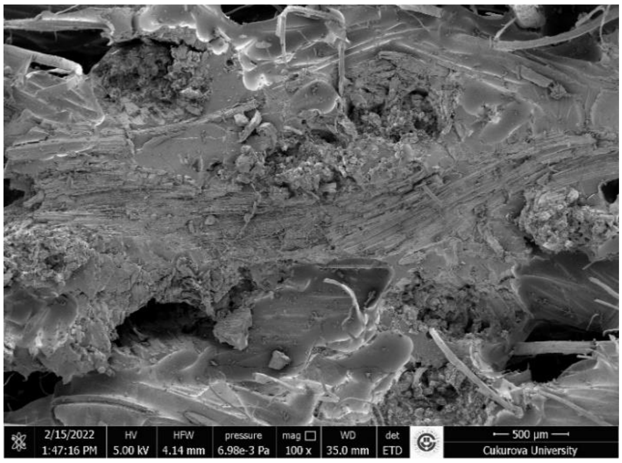


Figure 9. JE composites at 50°C post cure temperature SEM micrograph

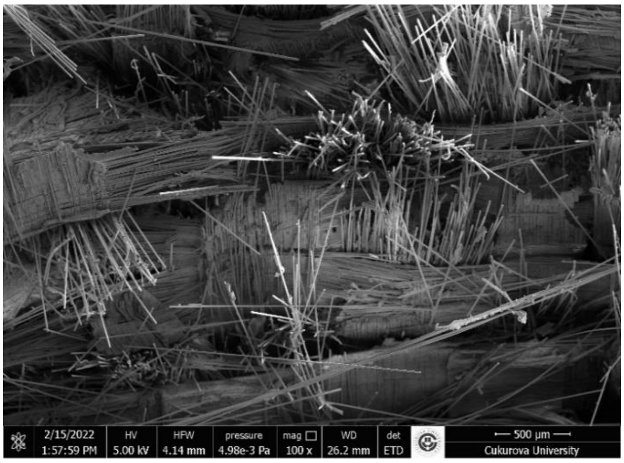


Figure 10. BE composites at 50°C post cure temperature SEM micrograph

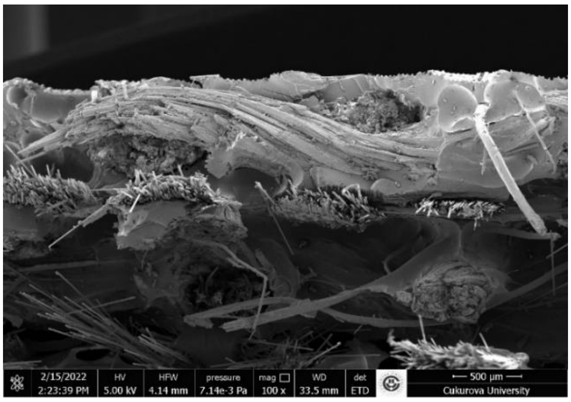


Figure 11. JBE composites at 50°C post cure temperature SEM micrograph

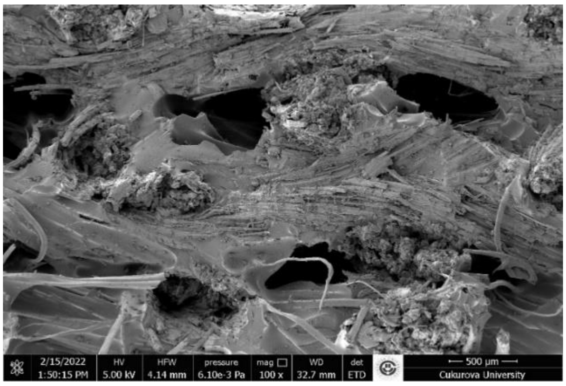


Figure 12. JE composites at 70°C post cure temperature SEM micrograph

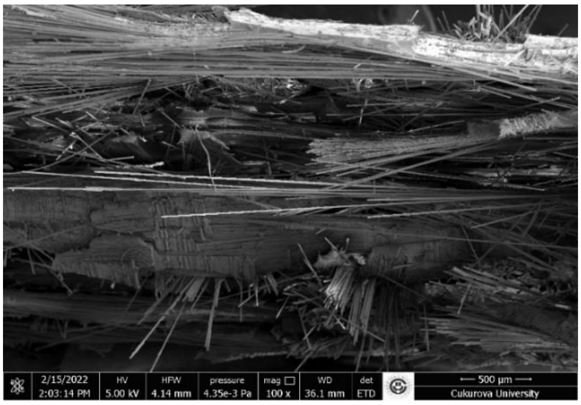


Figure 13. BE composites at 70°C post cure temperature SEM micrograph

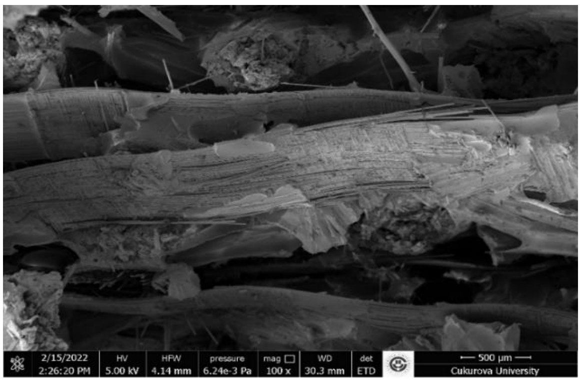


Figure 14. JBE composites at 70°C post cure temperature SEM micrograph

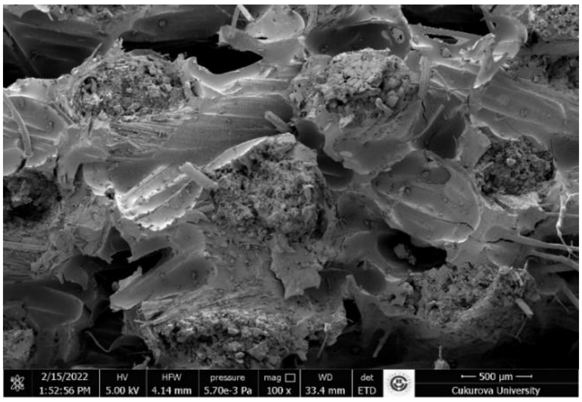


Figure 15. JE composites at 90°C post cure temperature SEM micrograph

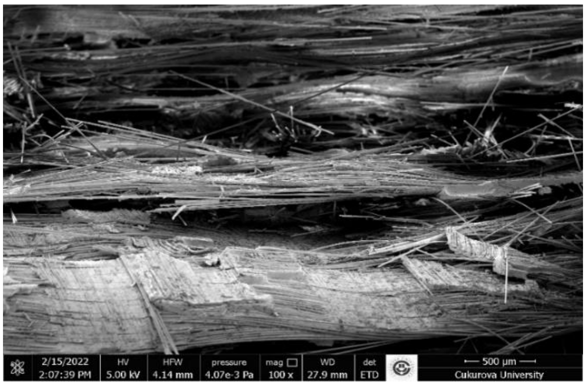


Figure 16. BE composites at 90°C post cure temperature SEM micrograph

Figure 17. JBE composites at 90°C post cure temperature SEM micrograph

4. Conclusions

In the present study, the effect of three different post-curing temperatures on the mechanical characteristics and water absorption rate of homogeneous and hybrid woven composites reinforced with jute and basalt fibers was investigated. The outcomes of the tensile tests demonstrated that increasing the post-cure temperatures from 50 °C to 90 °C resulted in an increase in tensile strength of 1.06 times for homogeneous jute fiber composites and 1.45 times for hybrid jute/basalt composites. For homogeneous basalt fibers, increasing the post-cure temperature from 50 °C to 70 °C brought about 1.08 times increment in tensile strength, while rising the post-cure temperature from 70 °C to 90 °C decreased the tensile strength value. Whereas increasing the post-cure temperature for hybrid composite samples improves the mechanical properties, increasing the post-cure temperature above 70 °C for homogeneous jute and basalt fibers commonly do not result in a positive increase in the mechanical features of the material. According to the results of the Vickers hardness test, both the homogeneous jute and basalt composites and the hybrid jute/basalt composites exhibited higher hardness values with increasing post-cure temperature. Elevated the post-cure temperature from 50 °C to 90 °C led to an increase of 1.36 times for homogeneous jute fiber composites, 1.19 times for homogeneous basalt fibers, and 1.35 times for hybrid jute/basalt fibers. The water absorption results show that the water absorption rate generally decreases with elevated post-cure temperature. This can be ascribed to the fact that the resin forms a stronger bond with the fibers and prevents it from interfering with the fiber-matrix interaction. The results of the SEM analysis also indicate that the data obtained from the physical examination of the homogeneous and hybrid composite structures confirm the results of the tensile tests. Although increasing post-cure temperatures have shown different effects on hybrid and homogeneous composite structures, increasing the post-cure temperature usually has a favorable impact on the mechanical features. In terms of both environmental impact and cost, the use of natural and mineral fiber reinforced composites by hybridization and application of high post-curing temperatures will exhibit superior characteristics for interior and exterior trim parts in the automotive industry compared to other hybrid structures.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Author Contributions

B. Karacor developed the methodology and experimental study. M. Ozcanli supervised and prepared the manuscript.

Nomenclature

J : Jute fabric
B : Basalt fabric
JE : Jute fiber reinforced homogeneous composite
BE : Basalt fiber reinforced homogeneous composite
JBE : Jute/ Basalt fiber reinforced hybrid composite
VARTM : Vacuum Assisted Resin Transfer Molding
ASTM : American Society of Testing Materials
HV : Hardness Value
SEM : Scanning Electron Microscope

References

1. Adam H., *Carbon fibre in automotive applications*. Materials and Design, 1997. **18**(4–6): p. 349–355.
2. Rajak D. K., D. D. Pagar, R. Kumar, and C. I. Pruncu, *Recent progress of reinforcement materials: A comprehensive overview of composite materials*. Journal of Materials Research and Technology, 2019. **8**(6): p. 6354–6374.
3. Ramli N., N. Mazlan, Y. Ando, Z. Leman, K. Abdan, A. A. Aziz, and N. A. Sairy, *Natural fiber for green technology in automotive industry: A brief review*. IOP Conference Series: Materials Science and Engineering, 2018. **368**(1): p. 012012.
4. Begum K. and M.A. Islam, *Natural Fiber as a substitute to Synthetic Fiber in Polymer Composites:A Review*. Research Journal of Engineering Sciences, 2013. **2**(3): p. 46–53.
5. Mohammed L., M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, *A Review on Natural Fiber Reinforced Polymer Composite and Its Applications*. International Journal of Polymer Science, 2015. **2015**: p. 1–15.
6. Bledzki A. K. and J. Gassan, *Composites reinforced with cellulose*. Progress in Polymer Science, 1999. **24**: p. 221–274.
7. Ali A., M. A. Nasir, M. Y. Khalid, S. Nauman, K. Shaker, S. Khushnood, K. Altaf, M. Zeeshan and A. Hussain, *Experimental and numerical characterization of mechanical properties of carbon/jute fabric reinforced epoxy hybrid composites*. Journal of Mechanical Science and Technology, 2019. **33**(9): p.4217–4226.
8. Alves C., P. M. C. Ferrao, A. J. Silva, L. G. Reis, M. Freitas, L. B. Rodrigues, D. E. Alves, *Ecodesign of automotive components making use of natural jute fiber composites*. Journal of Cleaner Production, 2010. **18**(4): p. 313–327.
9. Keya K. N. , N. A. Kona, F. A. Koly, K. M. Maraz, M. N. Islam, and R. A. Khan, *Natural fiber reinforced polymer composites: history, types, advantages, and applications*. Materials Engineering Research, 2019. **1**(2): p. 69–87.
10. Mohanty A. K., M. Misra, and G. Hinrichsen, *Biofibres, biodegradable polymers and biocomposites: An overview*. Macromolecular Materials and Engineering, 2000. **276–277**(1): p. 1–24.
11. Drzal L. T., A. K. Mohanty, and M. Misra, *Bio-composite materials as alternatives to glass fibre reinforced composites for automotive applications*. Magnesium, 2001. **40**: p. 386–390.
12. Jeyanthi S. and J. J. Rani, *Influence of natural long fiber in mechanical, thermal and recycling properties of thermoplastic composites in automotive components*. International Journal of Physical Sciences, 2012. **7**(43): p. 5765–5771.
13. Holbery J. and D. Houston, *Natural-fiber-reinforced polymer composites in automotive applications*. JOM, 2006. **58**(11): p. 80–86.
14. Chimeremeze C. P. and O. D. Anayo, *Economic Advantages and Sustainability of Basalt Civil / Structural Materials for Nigerian Modern Engineering Structures ; Positive Impact on Landfillıng Construction*. International Journal of Advances in Mechanical and Civil Engineering, 2019. **6**(2): p. 45–51.
15. Zhou H., B. Jia, H. Huang, and Y. Mou, *Experimental Study on Basic Mechanical Properties of Basalt Fiber Reinforced*

Concrete. Materials, 2020. **13**(6): p. 1362.

16. Tóth L. F, J. Sukumaran, G. Szebenyi, A. Kalacska, D. Fauconnier, R. Nagarajan and P. De Baets, *Large-scale tribological characterisation of eco-friendly basalt and jute fibre reinforced thermoset composites*. Wear, 2020. **450–451**(March): p. 203274.
17. Yuvaraj M., M. Rajmohan, G. Naveen, and S. Mohanraj, *Mechanical Characterisation of Basalt Based Composite Materials*. Proceedings of the IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 2014. (November): p. 70–76.
18. Bahrami M., J. Abenojar, and M. Á. Martínez, *Recent Progress in Hybrid Biocomposites: Mechanical Properties, Water Absorption, and Flame Retardancy*. Materials, 2020. **13**(22): p. 5145.
19. Cangül S., Ö. Adıgüzel, S. Tekin, F. Öztekin, and Ö. Satıcı, *A Comparison of the Water Absorption and Water Solubility Values of Four Different Composite Resin Materials*. Cumhuriyet Dental Journal, 2018. **21**(4): p. 335–342.
20. Fiore V., T. Scalici, F. Sarasini, J. Tirilló, and L. Calabrese, *Salt-fog spray aging of jute-basalt reinforced hybrid structures: Flexural and low velocity impact response*. Composites Part B: Engineering, 2017. **116**: p. 99–112.
21. Surana I., D. J. Pandya, N. H. Padmaraj, S. Hegde, and K. N. Chethan, *Influence of filler material on mechanical and vibration properties of basalt/epoxy composites*. Materials Research Express, 2019. **6**(8): p. 085342.
22. Kumar N. and A. Singh, *Study the effect of fiber orientation on mechanical properties of bidirectional basalt fiber reinforced epoxy composites*. Materials Today: Proceedings, 2021. **39**: p. 1581–1587.
23. Darshan S. M. and B. Suresha, *Effect of basalt fiber hybridization on mechanical properties of silk fiber reinforced epoxy composites*. Materials Today: Proceedings, 2021. **43**: p. 986–994.
24. Dhiman P. and H. Sharma, *Effect of walnut shell filler on mechanical properties of jute-basalt hybrid epoxy composites.* Materials Today: Proceedings, 2021. **44**: p. 4537–4541.
25. Kishore M., M. Amrita, and B. Kamesh, *Tribological properties of basalt-jute hybrid composite with graphene as nanofiller*. Materials Today: Proceedings, 2021. **43**: p. 244–249.
26. Alagarasan K., R. Ramkumar, and K. Dhanesh Prabu, *Fabrication and Mechanical Testing of Natural (Jute) Fibre Composite Material*. International Journal for Innovative Research in Science & Technology, 2016. **3**(06): p. 78–83.
27. Zareei N., A. Geranmayeh, and R. Eslami-Farsani, *Interlaminar shear strength and tensile properties of environmentally-friendly fiber metal laminates reinforced by hybrid basalt and jute fibers*. Polymer Testing, 2019. **75**(February): p. 205–212.
28. Almeida-Chetti V. A., R. L. Macchi, and M. E. Iglesias, *Effect of post-curing treatment on mechanical properties of composite resins*. Acta odontologica latinoamericana : AOL, 2014. **27**(2): p. 72–76.
29. Singh J. I. P., S. Singh, and V. Dhawan, *Effect of Curing Temperature on Mechanical Properties of Natural Fiber Reinforced Polymer Composites*. Journal of Natural Fibers, 2018. **15**(5): p. 687–696.
30. Ozkur S., M. Leskovšek, B. Golja, A. Demsar, H. Sezgin, and I. Yalcin-Enis, *Characterization of Thermo-mechanical and Morphological Properties of Jute Fabric Reinforced Epoxy/AESO Bio-composites*. Fibers and Polymers, 2021. **22**(12): p. 3414–3424.
31. Kumascı, Technical Properties of Jute(250 gr per metresquare). [cited 2021 28 Dec]; Available from https://www.kumasci.com/urun/kanavice-jut-telis-cuval-kumasi-ham-en-sik-jut-10-onz/1316.
32. Kompozitshop, Techinical properties of basalt fiber. [cited 2021 28 Dec]; Available from: https://www.kompozitshop.com/bazalt-fiber-kumas-200grm2-plain.
33. Kompozitshop, Epoxy and hardener. [cited 2021 28 Dec]; Available from: https: //www.kompozitshop.com/epoksi-recine-ve-sertlestirici.
34. ASTM D3039/D3039-M *Standard Test Method for Tensile Properties of Polymer Matrix Composite Material.*
35. ASTM E92-17 *Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials*.
36. ASTM D 5229/D 5229M – 92, *Standard test method for moisture absorption properties and equilibrium conditioning of polymer matrix composite materials*.
37. Mann G. S., L. P. Singh, and P. Kumar, *Experimental Investigation of Effect of Curing Temperature on Mechanical Properties of Hybrid Composites*. International Journal of Technical Research & Science, 2020. **05**(03): p. 10–15.
38. Cao S., Z. Wu, and X. Wang, *Tensile properties of CFRP and hybrid FRP composites at elevated temperatures*. Journal of Composite Materials, 2009. **43**(4): p. 315–330.
39. Karacor B. and M. Özcanlı, *Different Curing Temperature Effects on Mechanical Properties of Jute/Glass Fiber Reinforced Hybrid Composites*. International Journal of Automotive Science and Technology, 2021. **5**(4): p. 358–371.
40. Aruniit A. , J. Kers, A. Krumme, T. Poltimäe, and K. Tall, *Preliminary Study of the Influence of Post Curing Parameters to the Particle Reinforced Composite's Mechanical and Physical Properties*. Material Science(Medziagotyra), 2012. **18** (3): p. 256–261.
41. Almansour F. A., H. N. Dhakal, and Z. Y. Zhang, *Effect of water absorption on Mode I interlaminar fracture toughness of flax/basalt reinforced vinyl ester hybrid composites.* Composite Structures, 2017. **168**: p. 813–825.
42. Ramesh Kumar S. C. , R. V. P. Kaviti, L. Mahesh, and B. M. Mohan Babu, *Water absorption behavior of hybrid natural fiber reinforced composites*. Materials Today: Proceedings, 2022. **54**: p. 187-190.
43. Ramesh M., R. Vimal, K. H. Hara Subramaniyan, C. Aswin, B. Ganesh, and C. Deepa, *Study of Mechanical Properties of Jute-Banana-Glass Fiber Reinforced Epoxy Composites under Various Post Curing Temperature*. Applied Mechanics and Materials, 2015. **766–767**: p. 211–215.